ROBOTS IN THE TEXTILE AND FASHION INDUSTRIES: FACTS AND PROSPECTIVES

Pablo JIMÉNEZ-SCHLEGL & Goran ČUBRIĆ

Abstract: *Constant modernization and automation of production processes through the implementation of new technologies in the textile and fashion industry results in increased efficiency and better use of existing equipment. It is expected that the automation increases productivity and product quality, provides greater flexibility and reduces production process of finished product. New technologies, in this particular case the robotic technology, should facilitate and simplify the production processes. Despite its success in other industrial sectors, the use of robots in textile and fashion industry is rather limited. Main reason is a number of technical difficulties of dealing with a soft deformable textile materials. During handling, fabric can buckle, band or fold up. Moreover, during the sewing process, wrinkles and distortion can appear. This paper presents the trend of industrial robots application during the automation of production processes in the textile and fashion industry.*

Keywords: Robots, textile, clothing, handling

1. Introduction

When compared to traditional machines, robots offer a much higher degree of flexibility as they are not constrained to follow fixed trajectories but can switch easily between tasks, even including tool changes, and can be reprogrammed in an equally straightforward way. Compared to human workers, robots are more reliable (in general) as for repeatability and precision, they are less prone to errors, need no rest nor vacancies (besides occasional maintenance), and can work in hazardous or arduous conditions. Despite their success in other industrial sectors, the fact is that the textile industry has made a poor, if not merely symbolic, use of robots. This is not only because this industry is based –for several processes– on an economy of scale, with low flexibility, and on cheap manual work in underdeveloped countries, but mainly –maybe as the underlying reason– because of the technical difficulties of dealing with a soft deformable material like fabrics. Manipulating cloth parts or items is probably the most common operation to perform within the factory. It may appear as a principal task on its own, like e.g. in folding a garment for packing, but it appears also as a crucial auxiliary operation for other basic tasks like cutting and sewing.

Manipulating fabrics has many associated problems, due to the extreme deformability of this stuff and its propensity to form wrinkles, creases and folds. As said in [1], cloth displays a complex behaviour due to its highly intricate anisotropic and nonlinear mechanical response, where subtle mechanical actions are amplified into large draping or motion variations. The difficulties in manipulating cloth are systematically described in [2] for the three main phases of manipulation, namely grasping, moving and releasing, and are related to uncontrolled deformations, uncertainty about the number of grasped cloth items, entanglements, or unexpected releasing.

To this, we have to add the difficulties related to the identification of the type and of the configuration of the cloth item by means of computer vision, due to the richness of garment typology and the practically infinite inter-garment variability. As for the latter, we are dealing with objects whose shape shifts between a planar extended state (which may be completely flat, slightly or heavily wrinkled), and a set of folded states, which can in turn display an aleatory (like when the cloth is taken out from a wash bin) or an ordered fold pattern. These issues, together with the corresponding research lines and solutions devised so far are collected in Section 2.

Despite these problems, the two last decades have witnessed a growing research effort in robotic handling of cloth. While most of the research has been developed implicitly with domestic laundry chores in mind, and lately also focusing on dressing assistance applications of disabled people, many of their findings are general enough to be directly applicable to industrial settings. To this end, Section 3 is devoted to provide industrial practitioneers with an insight of the state of the art in the research of robot handling techniques of cloth and of the application possibilities in their environments.

Robots can perform other tasks besides handling, if equipped with the appropriate tools. Cutting is one of such tasks, which raises great interest in the textile and clothing context, as it constitutes the basic operation to perform on the textile sheet. In Section 4 we will revise the different cutting options as well as the possibilities of robotising this operation. The second main task is assembling the cut parts together to obtain a finished garment, by sewing. More than carrying a sewing head, robots are involved in the process by holding and guiding the parts to be sewn while maintaining a certain tension, i.e., to assist the sewing machine. Thus this task could be viewed as a special manipulation action. However, due to its specifity and particularities, as well as regarding its relevance, we have decided it was worthwile to consecrate sewing assistance its own section, namely 5.

With the structure implicitly sketched out in this Introduction we practically cover the whole subject of potential (and in some cases actual) robotization of processes in the textile industry, or at least of its main parts. Some final comments and suggestions are provided in Section 6.

2. Perception

The versatility and flexibility of robots is clearly conditioned by their perception abilities. The more the robotic system is informed about the actual and present circumstances of its environment, the more appropriate response it can provide through its actions. The most powerful input source is vision, with high discriminative capabilities as for the external features of the objects, i.e., their appearance. However, due to occlusions, ambiguities, bad illumination, etc. vision alone is sometimes not enough: in those cases, in a quite natural way, another perception source can complement vision and avoid such shortcomings, namely force sensing. These two perception types are examined next as for their application in the cloth and garments settings.

2.1 Vision

The most common use of computer vision in the industrial environment is failure detection and defect localization. In the textile and clothing industry, this may range from detecting weave defects in the fabrics to determine that the dimensions of a cut piece do not correspond to the specifications. This is a well-known and classical application of computer vision, and if used within a robotic cell or line, it may trigger the response of the robot retiring the faulty part. In this section, however, we are going to examine more non-conventional uses of vision.

2.1.1 Grasp point detection

The vision system has to determine at which point should the robot grasp the cloth item. This may be an arbitrary point to just pick up a cloth from an unordered pile, or specific points like the shoulders of a pullover, the waistline of trousers, the collar of a polo shirt, or even at a point corresponding to a node of a preexisting model of the garment piece. Extensive research has been done in this subject, which is closely related to state recognition.

2.1.2 Classification and state recognition

If different garment types or parts may be present at the production line, the vision system has to be able to discriminate (i.e., to classify) between them. Even if there is only one type of garment, computer vision may possibly be endowed with the task of distinguishing between different states, e.g. along a folding process. Computer vision methods, both in 2D and 3D, provide the necessary feature and shape recognition abilities, often trained with machine learning methods working on models or real images of the garments. These methods, together with grasp point recognition, are surveyed in [3].

2.1.3 Seam tracking

Seam tracking involves continuous image processing while sewing is taking place, i.e., it has to be a closed loop control process, for robustness reasons (due to wrinkle formation and inaccuracies in the robot). The main issue and responsibility of the vision system, as mentioned in Section 5.2 below, is to guarantee that seam allowance is kept within specifications. The control law in this case consists in a commanded rotation velocity of the cloth proportional to the estimated seam width error and the angle between the trajectory tangent and the direction of sewing (both measured from the images), which is achieved by the corresponding rotations of the gripper’s fingers [4] or of the simultaneous rotation of the two grippers in a bimanual manipulation. Occlusions of the stitching point by the pressing foot of the sewing machine lead to having to anticipate possible errors. A 2 1/2 D visual servo system which combines position-based and image-based approaches is followed in [5-7] which use both a panoramic camera mainly for presewing tasks (see Section 5.2) and a zoom-lenses equipped camera for the area near the needle. They do also address the issue of approximating curved edges with straight segments. Regarding the control technique, they discard model-based strategies due to difficulties in accurately predicting the behavior of fabrics, and resort to a fuzzy logic controller instead. Alternatively, edge sensors may be used instead of cameras. Line sensor arrays installed in front of the presser foot that can measure seam allowance error online [8, 9].

2.2 Force

Force is usually measured by using a Force/Torque (F/T) sensor mounted on the robot's wrist, just before the gripper. In handling applications, it can inform about accidental contacts with the environment, the force exerted during a cloth flattening operation (see Section 3.2), the degree of stretching out a held-up piece of cloth [10], or whether the grasping of a garment has been successful. The most demanding and critical use of F/T sensors is tensile force control in sewing applications. Here, the robot has to pull, with a force that has neither to be too low (to avoid the formation of wrinkles) nor too large (to avoid stick-slip phenomena between fabric and support as well as disturbances in the feeding system) [9]. The appropriate tension to be applied depends on the extensibility of the particular type of fabrics, and also on the seam direction with respect to the yarns [5]. Moreover, the fabrics properties are not constant during sewing, but nonlinear functions of the distance between the grasp point and the needle, which decreases with time [4,11].

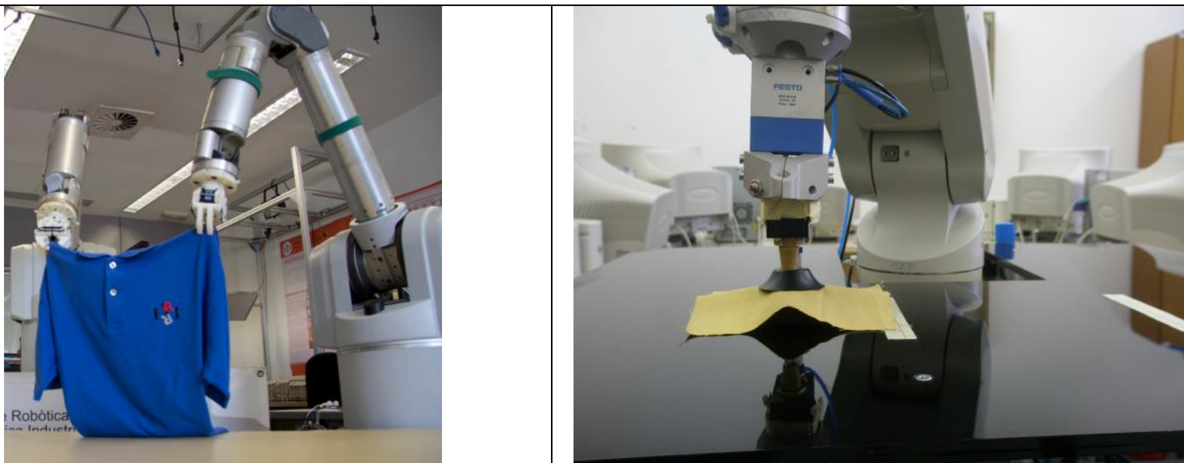
An alternative to use a wrist-located F/T sensor is to compute the end-effector forces from the torques exerted at the joints by the motors, or to estimate the external force applied to the robot from its dynamic behavior. This allows to obtain forces exerted on any point along the robot's arm. However, in [12, 13] this method is used to evaluate just an end-effector action: by their weight, the system discriminates how many garments (or if any at all) has grasped the robot from an unordered pile of similar pieces.

3. Handling

Handling is the basic material transference operation, but it comprehends many shapemodifying actions as well. As this kind of tasks is shared in different domains, these are the actions that also have received more attention from the research community.

3.1 Grasping

The textile and cloth industry has developed along the years different types of grasping devices, mounted on special purpose machines. Some of such grippers could actually be mounted on a robot. Such grasping devices are generally classified attending to the physical principle they are based on. In this sense, we can distinguish between mechanical impactive (pinch and/or clamp grippers) and ingressive (intrussive, i.e., needles, and nonintrusive like velcro and carden or brush), surface attraction which in turn can be based on suction (vacuum, Bernouilli, etc.) or electrostatic, and finally of the contigutive type, with the variants of chemical (washable) adhesion, thermal criogenic (freezing water), or thermal melting resin, figure 1.



a.	b.

Figure 1: Handling with robot, a. mechanical grasping of cloth, b. vacuum grasping of textile material

There is no ideal type of gripper for all kinds of fabrics and applications: ingressive grippers are contraindicated for handling delicate textiles, whereas leather should not be humidified, which invalidates criogenic gripping, or vacuum grippers do not work for very porous material like knitted wool. The most similar to an all-purpose gripper is precisely the most extended gripper type, namely the impactive one, as it is also the most similar to the human hand (although, in most cases, in the simplified twofingered version).

3.2 Manipulative actions

Next we list the basic manipulative actions with a short description and achievements attained so far.

- **Picking** usually means to separate a cloth part from the top of an ordered pile of identical parts, or to lift it from a table or similar surface. A typical requirement of this operation is to avoid deformations of the cloth part, which is satisfied by specialized ways of grasping, as seen above. In some cases it may also mean to take one item out of an unordered bunch. The critical sensing action is to determine where to grasp (see Section 2.1.1). Grasping is followed by a lifting or departing action, which should have no more difficulties than the standard ones of kinematic feasibility testing and collision avoidance.

- **Positioning by sliding on a surface (dragging and/or wiping)** is about changing the position of a fabric part lying on a surface like a table, while maintaining the fabric-surface contact. Interesting variants, from an industrial point of view, include dragging without deformations [14], wiping to create a crease at which to grasp the fabrics [15], or indirect simultaneous positioning, i.e. displacing a given cloth part towards the desired location of a specific set of unreachable positioned points by shifting another set of points, the manipulated points, to the destinations previously computed under a deformation model of the fabric item [16, 17].

- **Placing, laying** is also a positioning action, but now with an aerial approximation. In [18], different travelling directions and velocities have been tested, as well as the condition of obverse or reverse warpage, to determine the conditions of succesfull placing (without remaining folds).

- **Immobilizing** seeks to have full control on the cloth item’s shape, or part of it, determining how many fingers (grasp locations) are necessary and where they have to be located to immobilize arbitrary non-stretchable cloth polygons [19].

- **Flattening by sweeping, dragging and ironing** include all the techniques devised for eliminating wrinkles from flat lying cloth. Transversal sweeping motions [20] may not be enough if the wrinkle is to high, creating local looping folds instead. Longitudinal sweeps or combinations of sweeps with pinching and dragging actions can be used in such cases [21, 22]. Ironing is another cloth flattening task, analized for possible robotization in [23]. It should be noted that the so called robot iron from Siemens (Siemens Dressman TJ10500) isn’t actually a robot, but a special device for ironing (exclusively) shirts.

- **Unfolding**, spreading can be performed in a variety of ways, but the most common ones are unfolding on a table, by grasping a corner or an edge and spreading the overlapped fabric [24], or in the air (i.e., with the cloth item hanging from the manipulating grippers) combining gravity and rehandling until the garment is held at the same hemline by two grippers [25]. A flattening plus unfolding strategy is described in [26]. In any case, a vision system is required to certify the progress of the process, i.e., to determine the achievement of the successive states.

- **Folding** refers both to the individual action of bending and laying a cloth partially on itself, as well as to the sequence of single folds aimed at obtaining a given folded shape. A special gripper for grasping the cloth at two adjacent corners is built and used in [20] with a single robot, but the most common option is to resort to two coordinated robots. Folding takes places either on a surface like a table (recent references are [14, 21, 27-30]) or in the air [31]. The location and sequence of folds is generally known beforehand. Due to the symmetry of garments, manipulability can be considered to decide between equivalent sequences [14].

4. Cutting

When cutting fabrics, robots are faced with the dilemma whether to perform single-ply or multiple-ply (bundle) cutting. The latter, which may process up to 100 layers, is in principle much more efficient, but it is also more error-sensitive, as a single error affects a lot of fabrics and not just one layer. Bundle cutting comes inherently with another advantage: it provides automatically a buffer for the other sections along the processing of cloth. In contrast, it presents a very long in-process time (20-30 days vs. few hours) [32].

With respect to the cutting processes themselves, we may distinguish between the classical mechanical cutting procedures and the advanced ones. As for the first, GERBERcutters®, while not general-purpose robots, as they are specifically designed to perform exclusively cutting operations, share with standard robotic manipulators the capacity of easy reprogramming and switching between different cutting patterns. They provide conveyored single-ply and multiple-ply cutters, as well as single-ply static cutters. Others devices can considered as well, like Dekcell CNC oscillating knife cutter.

Advanced cutting includes laser, water-jet, and plasma cutting:

- Laser cutting requires focusing a powerful beam of light on a small area of fabrics. Beams are V-shaped, with a size of 0.004 of an inch. They may be oriented in different directions and exert no pressure on fabrics, which remains static. It is a high-speed and high accuracy process, but produces heat emission, which may possibly seal cut edges (this is an advantage in the case of fabric that ravels), and may also fuse together multiple plies (this disadvantage is not present when fabrics are not thermoplastic [32].

- Water-jet cutting involves a high pressure (70000 pounds per square inch) tiny water jet (0.001 to 0.0015 inch diameter). It allows to cut multiple-ply (although, after few layers the water power is severely retarded) without fusing, but may fray and tangle yarns of some fabrics. It is useful if heat has to be avoided and water absorption is not important. It requires filtering and deionization of water[32].

- Plasma jet cutting is indicated for single-ply, but it is cheaper than laser. In this process, an inert gas is blown at high speed out of the nozzle. At same time, an electrical arc is formed through the gas between the nozzle and the surface being cut, turning some of the gas to plasma. Plasma arcs reaches temperature up to 25000 ^{o}C and because of that is not commonly used for textile [33].

Robots equipped with cutting devices can certainly perform such operations. However, additional equipment is required to hold fabrics in place, mainly in the case of mechanical cutting which exerts pressure and therefore causes possible displacements in the material.

5. Sewing

In automated sewing, robots either carry a stitching head along the seam, or they assist a sewing machine. Next we explore both variants.

5.1 Sewing heads

In this first sewing variant, the robot is equipped with a sewing head instead of a gripper, and it is continuously carried along the seam line of a stationery work piece. This variant does not need feeding material system that is obligatory in conventional stitching machines.

Due to the specificity of 3D sewing with the existing traditional seam (lock stich 301), new types of stitching have been developed where the sewing head accesses to the work piece from one side. The simplest approach is a tufting process, where a needle pushes the thread into the material. Due to the friction between the thread and the material, the thread remains inside the material after pulling the needle. Another stitching type is the so called “one side stitching”. Here, one needle carries the thread penetrating through the material. The second needle, whose point is formed as a hook, also penetrates into material, grabs the loop made by the thread of the first needle and pulls it to the top.

In a second kind of sewing with two needles both carry the thread. A sewing thread loop formed by the first needle is taken up by the second needle and the chainstitch is created. Another way for connecting a textile material is by a blind stitch where the stitch impression is not showing on the right side of the garment. This type of sewing uses a curved needle that slightly penetrates the surface of the material and emerges on the same side as it enters. Besides sewing, the textile material can also be joint by welding. Materials suitable for welding must include 50-65% synthetic fibres [34-38].

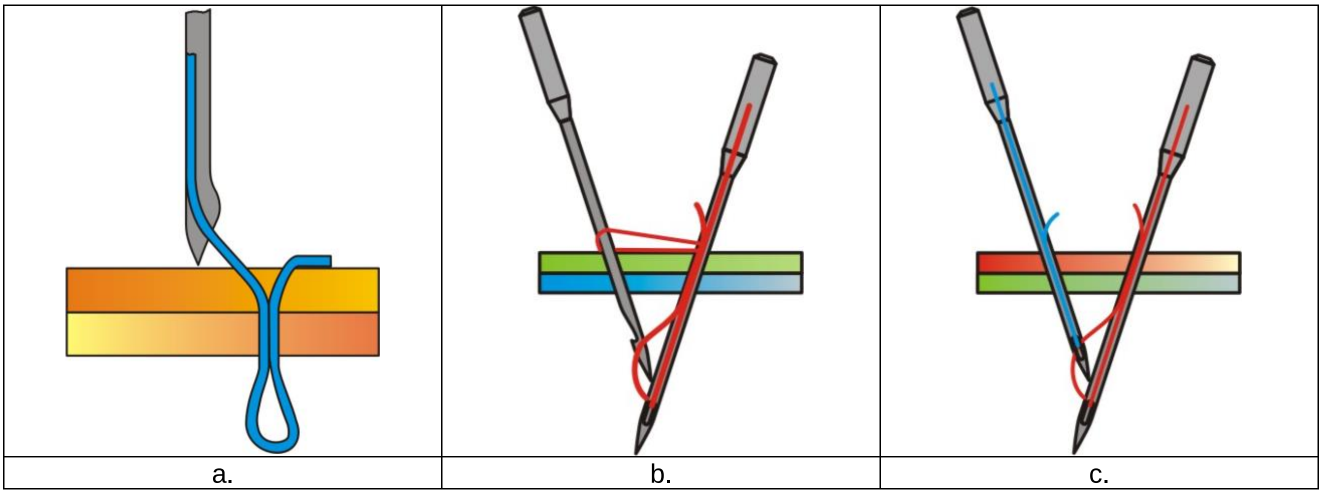


Figure 2: One side stitching, a. tufting, b. two needle – one thread, c. two needle – two thread

5.2 Sewing assistance

In the second variant the role of the robot consists in assisting a sewing machine by feeding and controlling the fabrics to be sewn. The robot grasps the cloth and guides it along a controlled trajectory. Sewing implies also a series of preliminary tasks, like the recognition of the fabric's shape by the camera system, the distinction of joining seams from decorative stitches, the planning of the sewing sequence, the extraction of the "seam line" by image processing (i.e., from the cloth panel's contour and considering the seam allowance –the distance between the fabric border and the seam– for the particular garment piece), and the initial positioning of the robot end-effector [5]. Planning obviously depends on the two first tasks, as the optimal sequence of sewing processes is conditioned by the shape of the panels to be sewn and decorative seams (involving only one cloth layer) should be sewn before union seams. This planning affects exclusively the sequencing of sewing operations, as for the execution of sewing itself online tracking (and seam line extraction) is required (see Section 2.1.3). In between these preliminary tasks and the sewing itself, a manipulative robot may also be responsible of adequately positioning the cloth at the point under the needle where sewing has to start.

Manipulation during the sewing process can be performed either with a single robotic arm [4-6] or be based on a bimanual system [9, 39]. In any case, the fabric is pulled forward by the sewing machine's feed mechanism (the feed dogs). The duties of the robot, which is holding the fabric behind the needle in the direction of advance, are twofold: to rotate the fabric panel around the needle to keep seam allowance within specifications, and maintaining a certain tensional state in the fabrics to prevent seam buckling or puckering. This involves to control positional accuracy (the stitching has to keep seam allowance within certain tolerances), velocity (both in direction, to adjust to possible changes in the seam orientation, as well as in module to ensure a uniform stitching, depending on the sewing machine shaft velocity), and tension (to avoid seam puckering, as described in Section 2.2). Additionally, robots have to maintain the fabrics flat against the table, which conditions the most extended grasping solution to be just downwards pressing fingers.

Quite recently Jonathan Zornow has presented Sewbo, a system that allow easy manipulation of cloth for sewing, by chemically stiffen fabrics, drenching it into a washable liquid polymer

6. Conclusions

The expansion of robotized solutions falls within the flexible production paradigm, which allows the apparel and fashion industry to evolve from an economy of scale towards an economy of scope [40] (the benefits of robot-driven flexibility in the apparel industry was identified quite earlier, see for example [41]). The authors identify three characterising manufacture sections along garment production, namely the storage and the retrieval processes of fabric from the warehouse in preparation for manufacture, the laying and cutting processes of garment components, and the assembly and sewing processes of garments. It is in the latter two sections where cloth is actually handled as soft material (the first one is rather about cloth rolls managing, except maybe for the last process in this section, which is inspection and defect-mapping). Among the basic tasks where robots (may) appear manipulating cloth parts there are picking up (a variant is separating from a pile), laying/positioning and immobilizing, sewing, ironing/pressing, inspecting, folding and packaging. In this paper, we have grouped all these actions within generic handling tasks, cutting and sewing. We have shown that the state of the art in research is ripe for its application in real industrial settings.

References

[1] Magnenat-Thalmann, N. & l Volino, P.: From early draping to haute couture models: 20 years of research, *The Visual Computer*, **Vol.** 21, No. 8 (2005), pp. 506–519.
[2] Gualtiero Fantoni, Marco Santochia, Gino Dinia, Kirsten Tracht, Bernd ScholzReiter, Juergen Fleischer, Terje Kristoffer Lien, Guenther Seliger, Gunther Reinhart, Joerg Franke, Hans Nrgaard Hansen, and Alexander Verl. Grasping devices and methods in automated production processes. CIRP Annals - Manufacturing Technology, 2014.
[3] Pablo Jiménez, "Visual Grasp Point Localization, Classification and State Recognition in Robotic Manipulation of Cloth: an Overview", Robotics and Autonomous Systems, 92: 107-125, 2017.
[4] David Gershon. Parallel process decomposition of a dynamic manipulation task: robotic sewing. Robotics and Automation, IEEE Transactions on, 6(3):357–367, Jun 1990.
[5] Panagiotis N. Koustoumpardis, Paraskevi Zacharia, and Nikos A. Aspragathos. Intelligent robotic handling of fabrics towards sewing. In Industrial Robotics, chapter 28, pages 559–581. 2006.
[6] Paraskevi Zacharia. Robot handling fabrics towards sewing using computational intelligence methods. In Dr. Ashish Dutta, editor, Robotic Systems - Applications Control and Programming, pages 61–84. 2012.
[7] Paraskevi Th. Zacharia, Nikos A. Aspragathos, Ioannis G. Mariolis, and Evangelos Dermatas. A robotic system based on fuzzy visual servoing for handling flexible sheets lying on a table. Industrial Robot, 36(5):489–496, 2009.
[8] J. Schrimpf, M. Lind, and G. Mathisen. Real-time analysis of a multi-robot sewing cell. In Industrial Technology (ICIT), 2013 IEEE International Conference on, pages 163–168, Feb 2013.
[9] J. Schrimpf, L.E. Wetterwald, and M. Lind. Real-time system integration in a multirobot sewing cell. In Intelligent Robots and Systems (IROS), 2012 IEEE/RSJ International Conference on, pages 2724–2729, Oct 2012.
[10] CloPeMa Consortium. The robot - clopema - clothes perception and manipulation, 2015.
[11] Panagiotis N. Koustoumpardis and Nikos A. Aspragathos. Intelligent hierarchical robot control for sewing fabrics. Robotics and Computer-Integrated Manufacturing, 30(1):34–46, 2014.
[12] Adri`a Colom´e, Diego Pardo, Guillem Aleny`a, and Carme Torras. External force estimation for textile grasp detection. In Intelligent Robots and Systems (IROS), Workshop: Beyond Robot Grasping-Modern Approaches for Learning Dynamic Manipulation, 2012 IEEE International Conference on, 2012.
[13] Adri`a Colom´e, Diego Pardo, Guillem Alenya`, and Carme Torras. External force estimation during compliant robot manipulation. In Robotics and Automation (ICRA), 2013 IEEE International Conference on, pages 3535–3540, May 2013.
[14] Karthik Lakshmanan, Apoorva Sachdev, Ziang Xie, Dmitry Berenson, Ken Goldberg, and Pieter Abbeel. A constraint-aware motion planning algorithm for robotic folding of clothes. In Jaydev P. Desai, Gregory Dudek, Oussama Khatib, and Vijay Kumar, editors, Experimental Robotics, STAR 88, volume 88 of Springer Tracts in Advanced Robotics, pages 547–562. Springer, 2012.
[15] Mizuho Shibata, Tsuyoshi Ota, and Shinichi Hirai. Wiping motion for deformable object handling. In 2009 IEEE International Conference on Robotics and Automation, ICRA 2009, Kobe, Japan, May 12-17, 2009, pages 134–139, 2009.
[16] Shinichi Hirai. Indirect simultaneous positioning of deformable objects by redundant fingers without physical parameters. In Complex Systems Intelligence and Modern Technological Applications (CSIMTA 2004), pages 509–514, 2004.
[17] T. Wada, S. Hirai, S. Kawamura, and N. Kamiji. Robust manipulation of deformable objects by a simple pid feedback. In Robotics and Automation, 2001. Proceedings 2001 ICRA. IEEE International Conference on, volume 1, pages 85–90, 2001.
[18] Mizuho Shibata, Tsuyoshi Ota, Yoshimasa Endo, and Shinichi Hirai. Handling of hemmed fabrics by a single-armed robot. In 4th IEEE Conference on Automation Science and Engineering, Key Bridge Marriott, Whashington DC, USA, pages 882– 887, 2008.
[19] Matthew P. Bell and Devin J. Balkcom. Grasping non-stretchable cloth polygons. Int. J. Robotics Research, 29(6):775–784, 2010.
[20] K. Paraschidis, Nikolaos Fahantidis, Vassilios Petridis, Zoe Doulgeri, Loukas Petrou, and Georgios Hasapis. A robotic system for handling textile and non rigid flat materials. Computers in Industry, 26(3):303–313, August 1995.

[21] Alex X. Lee, Henry Lu, Abhishek Gupta, Sergey Levine, and Pieter Abbeel. Learning force-based manipulation of deformable objects from multiple demonstrations. In IEEE International Conference on Robotics and Automation, ICRA 2015, Seattle, WA, USA, 26-30 May, 2015, pages 177–184, 2015.
[22] Li Sun, Gerardo Aragon-Camarasa, Simon Rogers, and J.Paul Siebert. Accurate garment surface analysis using an active stereo robot head with application to dualarm flattening. In 2015 IEEE International Conference on Robotics and Automation (ICRA), pages 185–192, May 2015.
[23] J.S. Dai. Task analysis and motion generation for service robots: With reference to region segregation and path generation for robotic ironing. chapter 3, pages 30–50. 2012.
[24] Eiichi Ono, Noboyuki Sakane, and Shigeyuki Sakane. Unfolding folded fabric using outline information with vision and touch sensors. Journal of Robotics and Mechatronics, 10(3):235–243, 1998.
[25] Kyoko Hamajima and Masayoshi Kakikura. Planning strategy for task of unfolding clothes. Robotics and Autonomous Systems, 32(2–3):145–152, 2000.
[26] Brian. Willimon, Stan Birchfield, and Ian Walker. Model for unfolding laundry using interactive perception. In Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on, pages 4871–4876, Sept 2011.
[27] Benjamin Balaguer and Stefano Carpin. Combining imitation and reinforcement learning to fold deformable planar objects. In Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on, pages 1405–1412, Sept 2011.
[28] Jeremy Maitin-Shepard, Marco Cusumano-Towner, Jinna Lei, and Pieter Abbeel. Cloth grasp point detection based on multiple-view geometric cues with application to robotic towel folding. In International Conference on Robotics and Automation (ICRA, pages 2308–2315, 2010.
[29] Stephen Miller, Mario Fritz, Trevor Darrell, and Pieter Abbeel. Parametrized shape models for clothing. In International Conference on Robotics and Automation (ICRA), pages 4861–4868, 2011.
[30] Georgios Zoumponos and Nikos Aspragathos. A fuzzy strategy for the robotic folding of fabrics with machine vision feedback. Industrial Robot, 37(3):302–308, 2010.
[31] Yuji Yamakawa, Akio Namiki, and Masatoshi Ishikawa. Motion planning for dynamic folding of a cloth with two high-speed robot hands and two high-speed sliders. In Robotics and Automation (ICRA), 2011 IEEE International Conference on, pages 5486–5491, May 2011.
[32] Encyclopaedia of textiles: Textile automation" edited by P. V. Vidyasagar, Mittal Publications, 2000
[33] Ineta Vilumsone-Nemes: Industrial Cutting of Textile Materials,Woodhead Publishing Limited, Elsevier, , 2012, ISBN 978-0-85709-556-5
[34] Wittig J.: Recent development in the robotic stitching technology for textile structural composites, Journal of Textile and Apparel, Technology and Management, Vol. 2, No. 1, 2001.
[35] Corves B: Mechatronics and Mechanisms: From Drive to Process, Proceedings of the 10th IFToMM International Symposioum on Science of Mechanisms and Machines, (Ed.) Visa I., Brasov, Romania, October 12-15, 2009., pp 15-46.
[36] Pribar Jana: Assembling technologies for functional garments – An overview, Indian Journal of Fibre & Textile Research, vol. 36, 2011, pp380-387.
[37] Ian Jones: Improving productivity and quality with laser seaming of fabrics, Technical Textiles International, 2005
[38] Nikolić, G et al: Robots and use in textile and clothing industry (in Croatian), 2008.
[39] Makoto Kudo, Yasuo Nasu, Kazuhis Mitobe, and Branislav Borovac. Multi-arm robot control system for manipulation of flexible materials in sewing operation. Mechatronics, 10(3):371–402, 2000.
[40] R. C. Michelini and R. P. Razzoli. Robotics in clothes manufacture. International Journal of Mechanical Engineering and Applications, 1(1):17–27, 2013.
[41] Paul M. Taylor, A.J. Wilkinson, I. Gibson, M.B. Gunner, and G.S. Palmer. An integrated automated garment assembly system. In Systems Engineering, 1990., IEEE International Conference on, pages 383–386, Aug 1990.

Pablo JIMÉNEZ-SCHLEGL, PhD
Institut de Robòtica i Informàtica Industrial, Polytechnical University of Catalonia
Llorens i Artigas, 4-6, 08028, Barcelona, Spain
Phone: +(34) (93) 4015784 E-mail: pjimenez@iri.upc.edu

Assist. Prof. Goran Čubrić, PhD
University of Zagreb Faculty of Textile Technology
Prilaz baruna Filipovića 28a, 10000, Zagreb, Croatia
Phone: +(385) (1) 3712555 E-mail: goran.cubric@ttf.hr